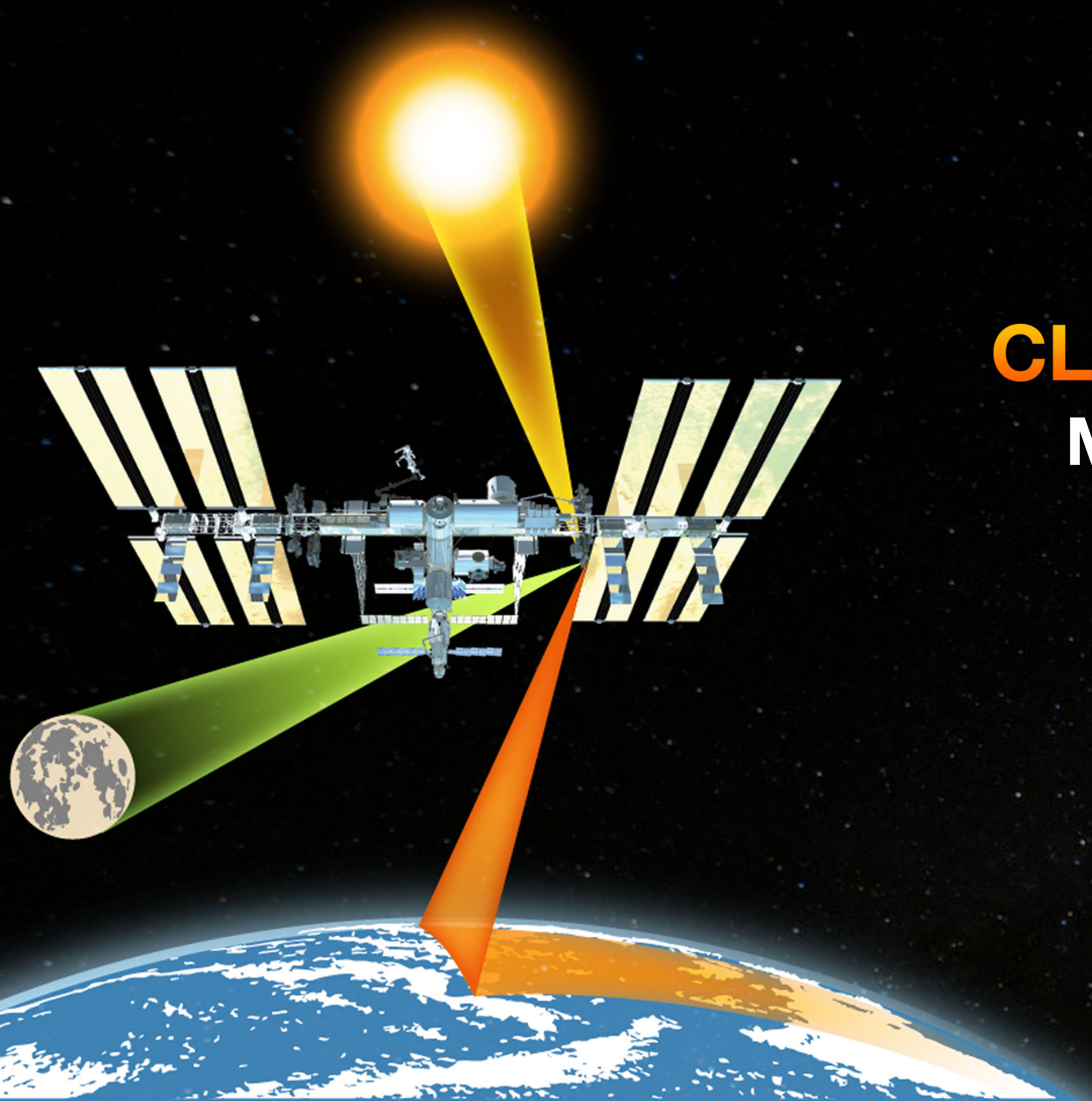

National Aeronautics and Space Administration

CLARREO Pathfinder

Mission Overview and its Intercalibration Capabilities

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NASA Langley Research Center

American Meteorological Society
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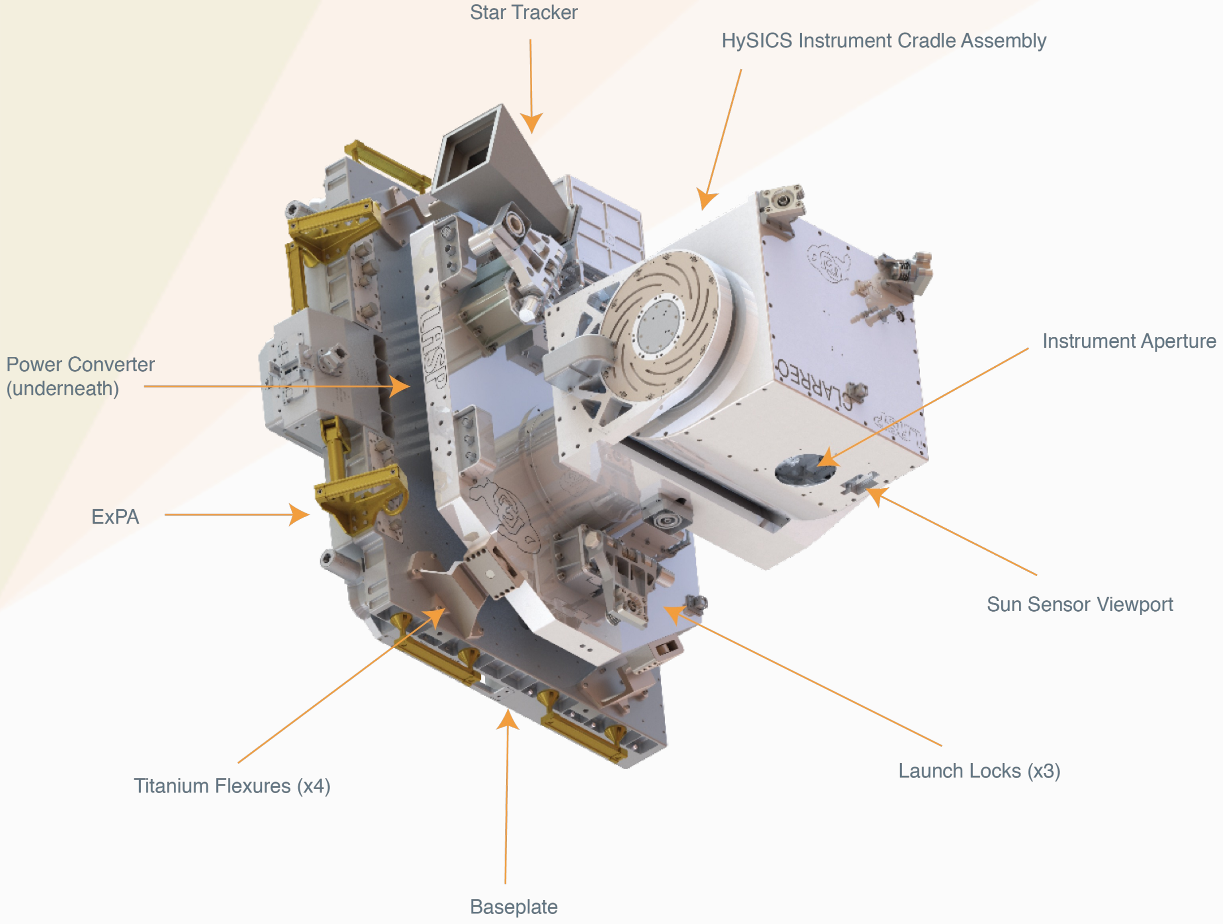
CLARREO Pathfinder Payload

HySICS: HyperSpectral Imager for Climate Science



Push-broom spectrometer

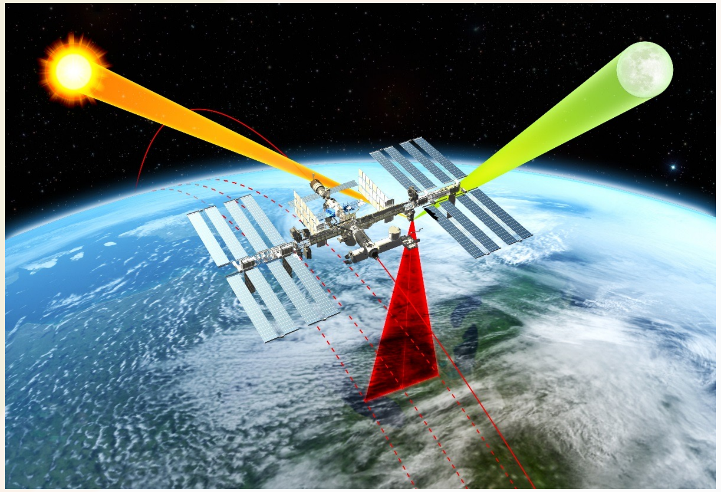
Spectral Range	350 nm – 2300 nm
Spectral Sampling	3 nm
Radiometric Uncertainty	0.3% (1-sigma)
Swath Width	10° (70 km nadir)
Spatial Sampling	0.5 km
Platform	ISS

https://clarreo-pathfinder.larc.nasa.gov/

CPF Science Objectives

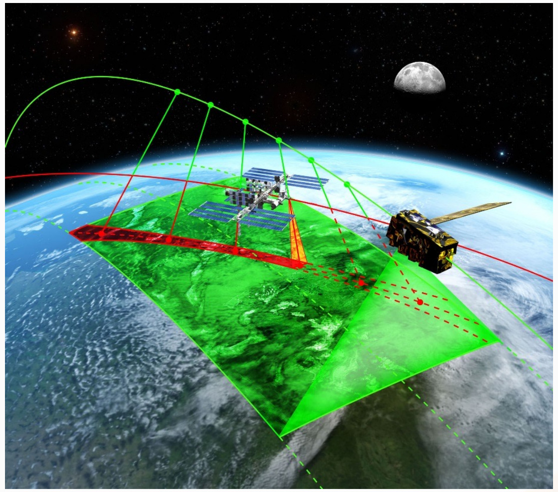
CLARREO Pathfinder

Objective #1: High Accuracy SI-Traceable Reflectance Measurements



Demonstrate on-orbit calibration ability to reduce reflectance uncertainty by a factor of ***5-10 times*** compared to the best operational sensors on orbit.

Objective #2: Inter-Calibration Capabilities



Demonstrate ability to transfer calibration to other key RS satellite sensors by inter-calibrating with CERES & VIIRS.

	Objective #1	Objective #2
Uncertainty	Spectrally-resolved & broadband reflectance: ≤0.3% (1σ)	Inter-calibration **methodology** uncertainty: ≤0.3% (1σ)
Data Product	Level 1A: Highest accuracy, best for inter-cal, lunar obs Level 1B: Approx. consistent spectral & spatial sampling, best for science studies using nadir spectra	Level 4: One each for CPF-VIIRS & CPF-CERES inter-cal. Merged data products including all required info for inter-cal analysis

https://clarreo-pathfinder.larc.nasa.gov/

Intercalibration: *A multidimensional data matching challenge!*

Spatial/Temporal Matching

- Spatial pixel resolution difference
- Non-zero temporal gap
- Mitigation: Use larger intercalibration footprints

Spectral Differences

- Scene dependent biases
- Accurate SBAF estimates needed for correction
- Hyperspectral measurements with <4nm sampling desired

Viewing/Solar Geometry

- May induce systematic biases
- Scene dependent corrections

Polarization Sensitivity

- Differing polarization sensitivity between Reference and Target
- Results in additional uncertainty in measuring polarized radiances
- Scene- and angle dependent

Miscellaneous

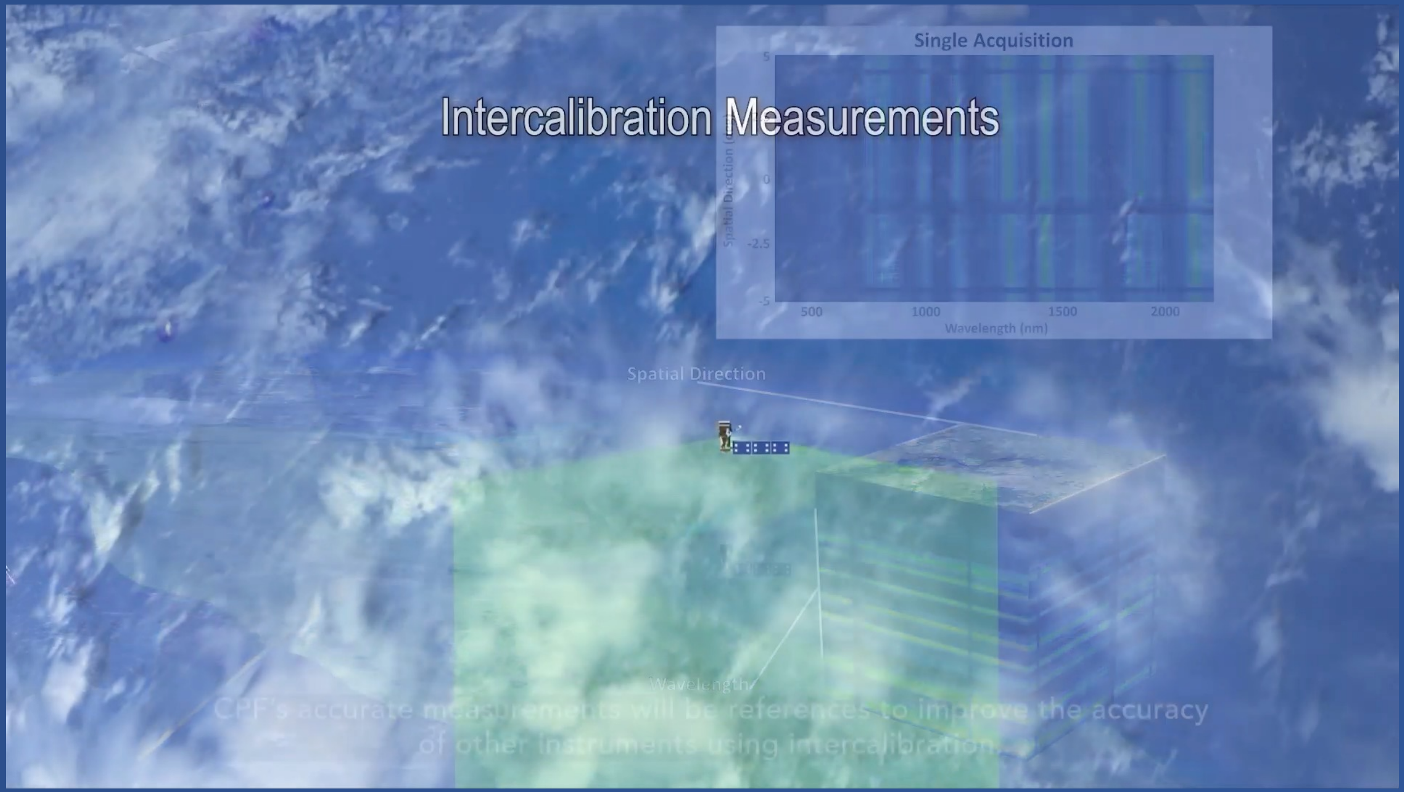
- Disparity in usage of reference solar spectra
- Scan-angle calibration dependency
- Sensor non-linearity

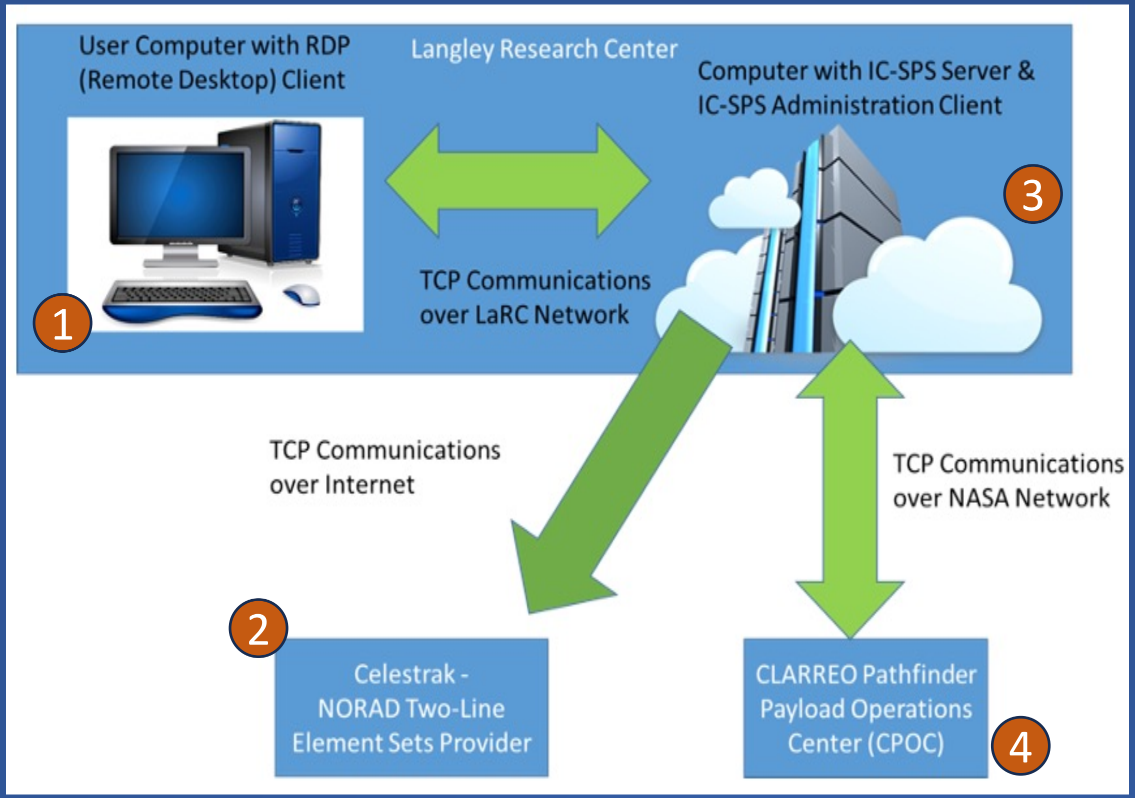
- In an idealized intercalibration setup, both the reference and target satellite instruments would acquire measurements that perfectly match in ***time***, ***space***, ***spectral response***, and ***viewing and solar geometry***
- CPF has developed ***novel algorithms*** to ***systematically analyze data matching uncertainties*** and substantially mitigate their impacts to achieve ***unprecedented intercalibration accuracy***

CPF as a SI-traceable Intercalibration reference

- CPF exhibits the most advanced amalgamation of *spectral range*, *spectral/spatial resolution*, and *radiometric accuracy*, positioning it as the future benchmark for in-orbit intercalibration
- CPF's 3-nm hyperspectral sampling enables the creation of pseudo multispectral channels that perfectly align with the spectral response functions of the target sensor, eliminating the requirement for SBAF
- *CPF will demonstrate a state-of-the-art intercalibration methodology (0.3% uncertainty at k=1) to accurately transfer the benchmark CPF calibration reference to CERES and VIIRS instruments*

Intercalibration Science Planning System (IC-SPS)

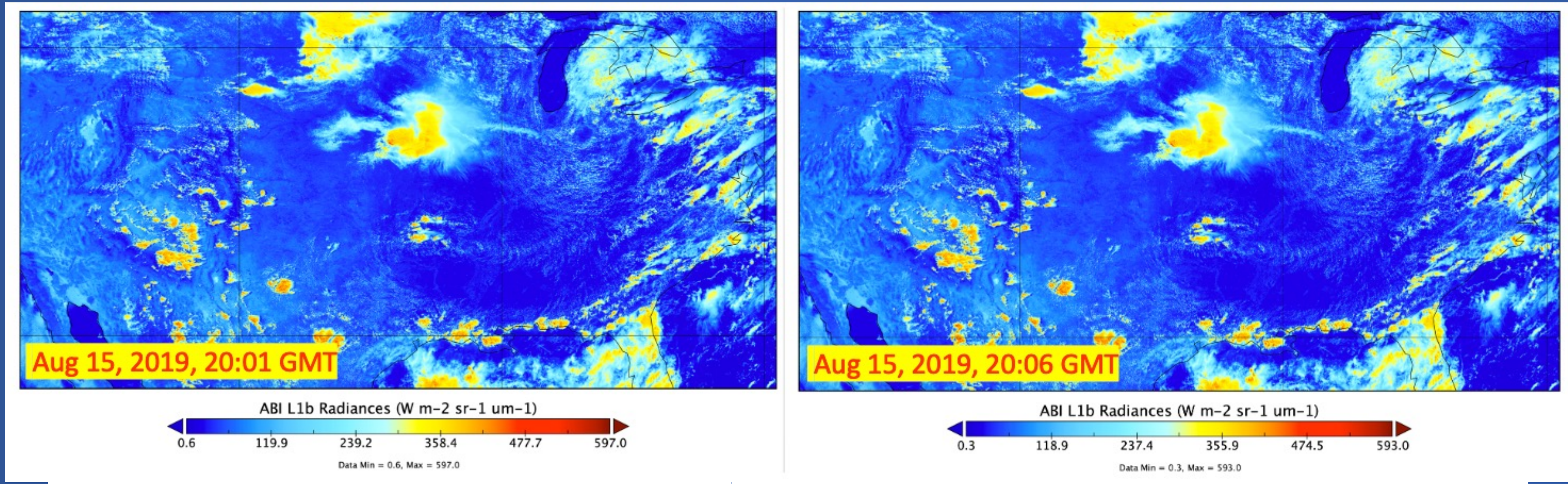


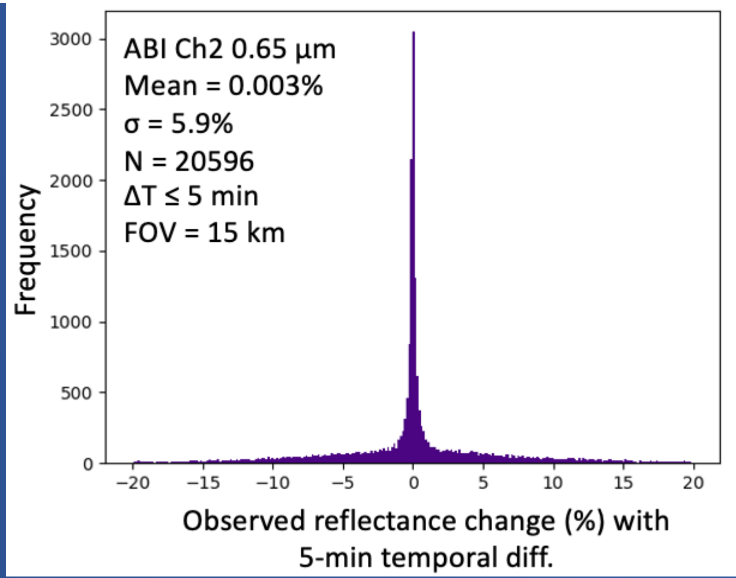


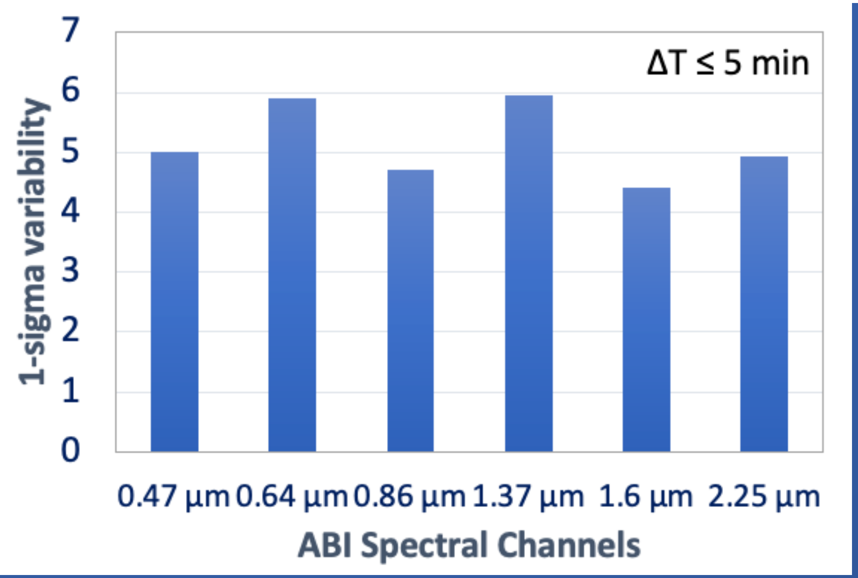
- IC-SPS is a custom developed software tool at LaRC to accurately predict intercalibration opportunities and provide that information to CPF Operations Center
- Other variants:
  - LASICS: Generalized intercalibration event predictor- critical tool for the *Satellite Severe Convection Research Group at LaRC* (successfully identified every convective cell observed by MODIS and AMSR-E over the US from 2002-2011)
  - GCP: Ground Control Point predictor to support CPF geolocation validation
  - ARCSTONE

Spatial/Temporal Data Matching Strategy

- Comprehensive and systematic evaluation of spatial and temporal matching uncertainties, considering spatial footprint size, scene homogeneity, and spectral channels as variables
- Extension of 2008 Wielicki et al. study



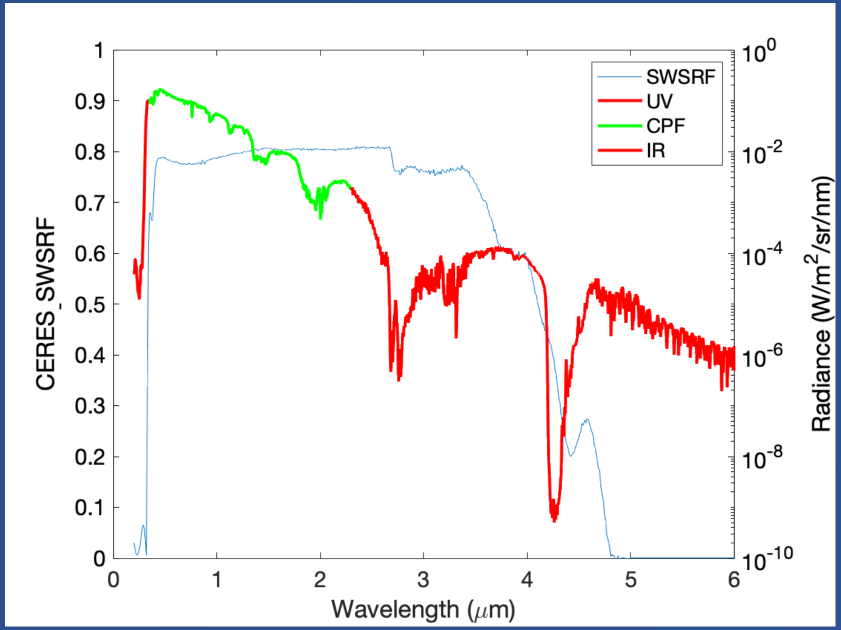




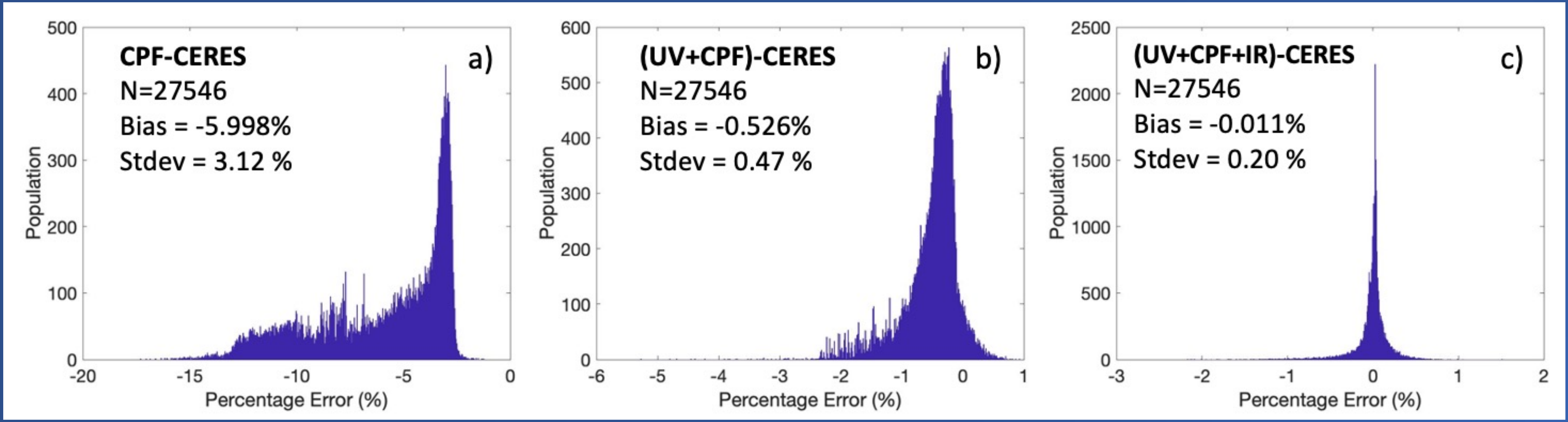
$$\boldsymbol{u} = \frac{\boldsymbol{\sigma}}{\sqrt{\boldsymbol{N}}}$$

$\boldsymbol{\sigma}$ determines req. num. of intercal samples to limit data matching uncertainty below a given threshold (targeted $\boldsymbol{u}$ = 0.1%)

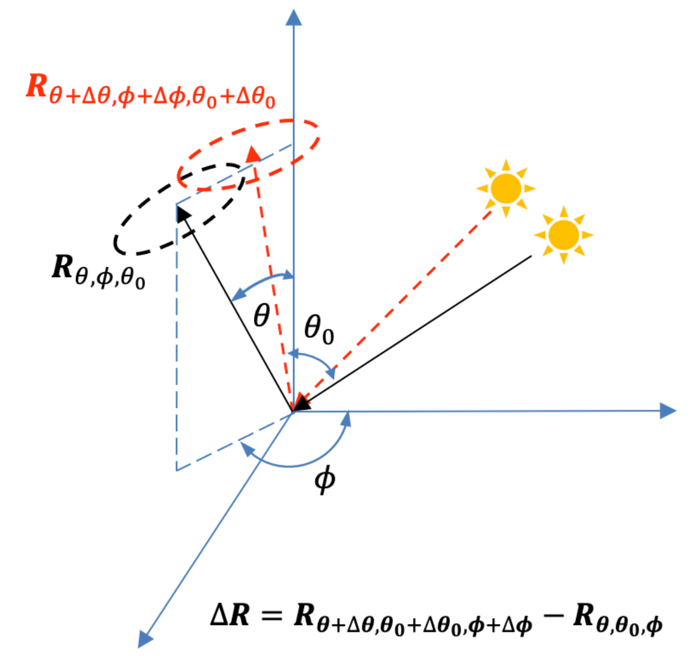
PCRTM-based Spectral Extension

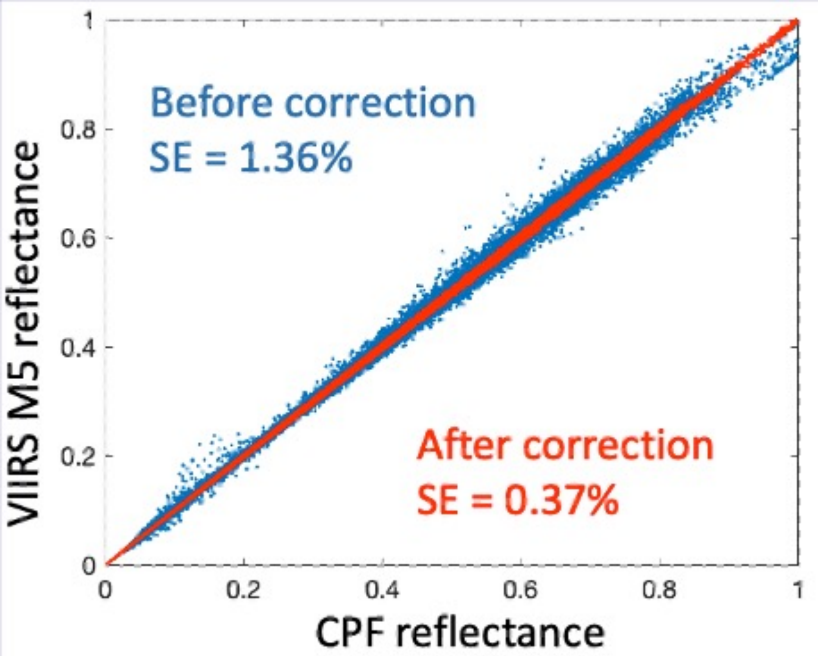


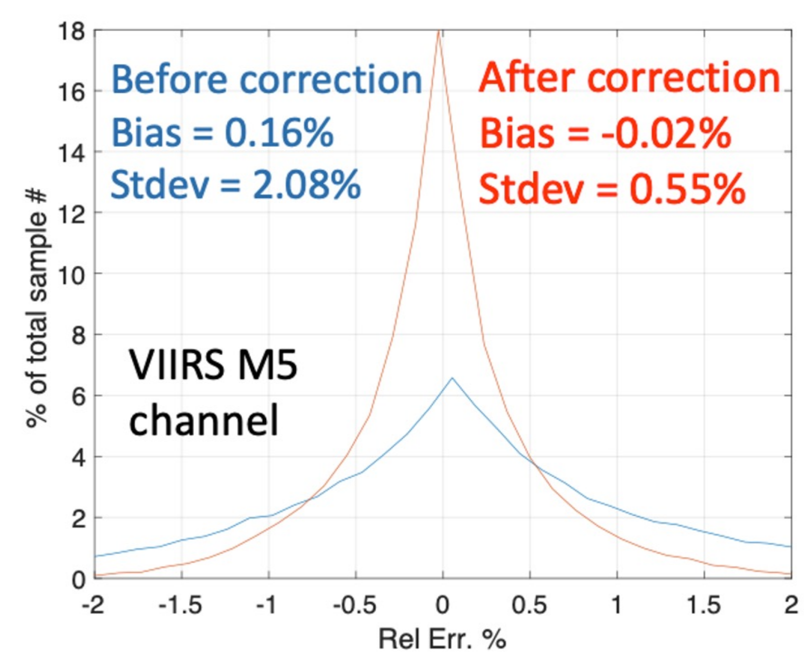
- CPF measurements must be extended to 200 nm – 5 μm to intercalibrate CERES SW channel
- Leverages spectrally redundant information available in the CPF-measured portion using Principal Component Analysis and utilize pre-established *spectral correlation relationships* among wavelengths to extend the CPF spectrum below 350 nm and above 2300 nm
- Anticipated *1-σ uncertainty < 0.1%*



PCRTM-based Angular Correction

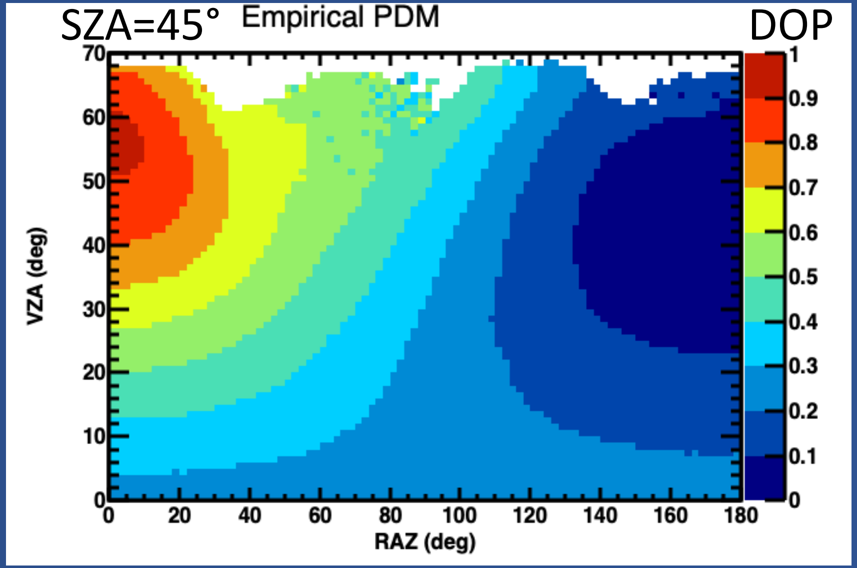


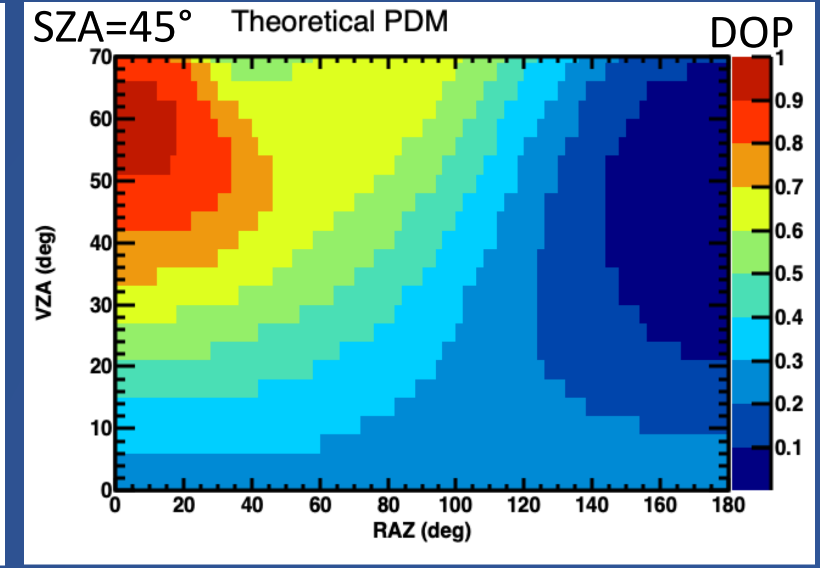




- CPF team has developed a PCRTM-based algorithm for angular adjustment
- Extensive training database consisting of millions of CPF-like spectral radiances encompassing diverse surface types and atmospheric conditions and SZA-VZA-RAA combinations that cover the entire range of possible viewing and solar angles
- Leverages ***spectral correlation relationship*** to account for differences between observations acquired at slightly different sun-view geometries
- Significant reduction of bias and noise after angular correction (uncertainty goal = 0.1%)

Novel Polarization Distribution Models (PDMs)





Disparity between diattenuation coefficient of CPF and VIIRS result in differing reflectance measurements

- Contribute to random and systematic uncertainty
- PDMs will be used for identifying low polarized intercalibration footprints

Empirical PDM for Clear-Sky Ocean (0.67 µm)

- Constructed using PARASOL/POLDER Data
- 3 wavelengths: 490, 670, and 865 nm

Theoretical PDM for Clear-Sky Ocean (0.67 µm)

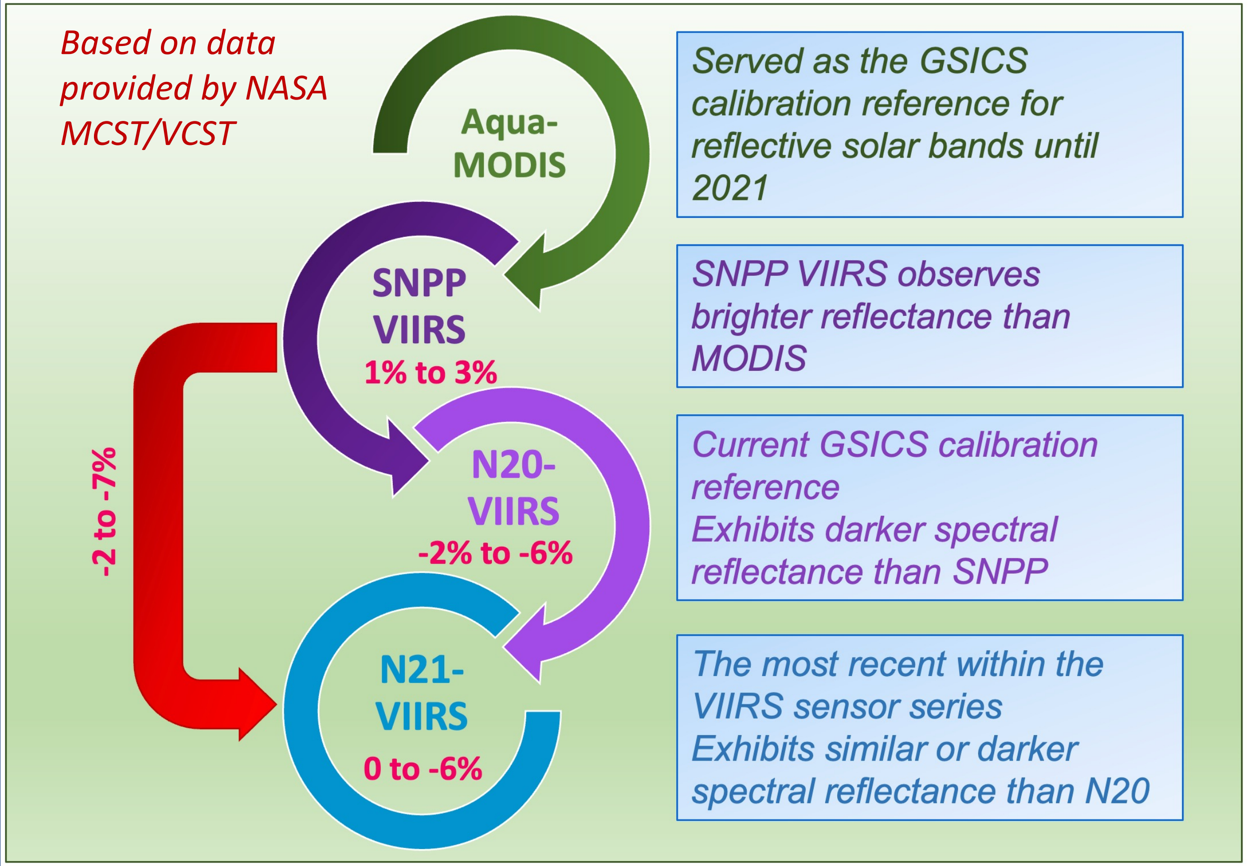
- Simulated using Adding-Doubling Radiative Transfer Model
- Covers all VIIRS bands

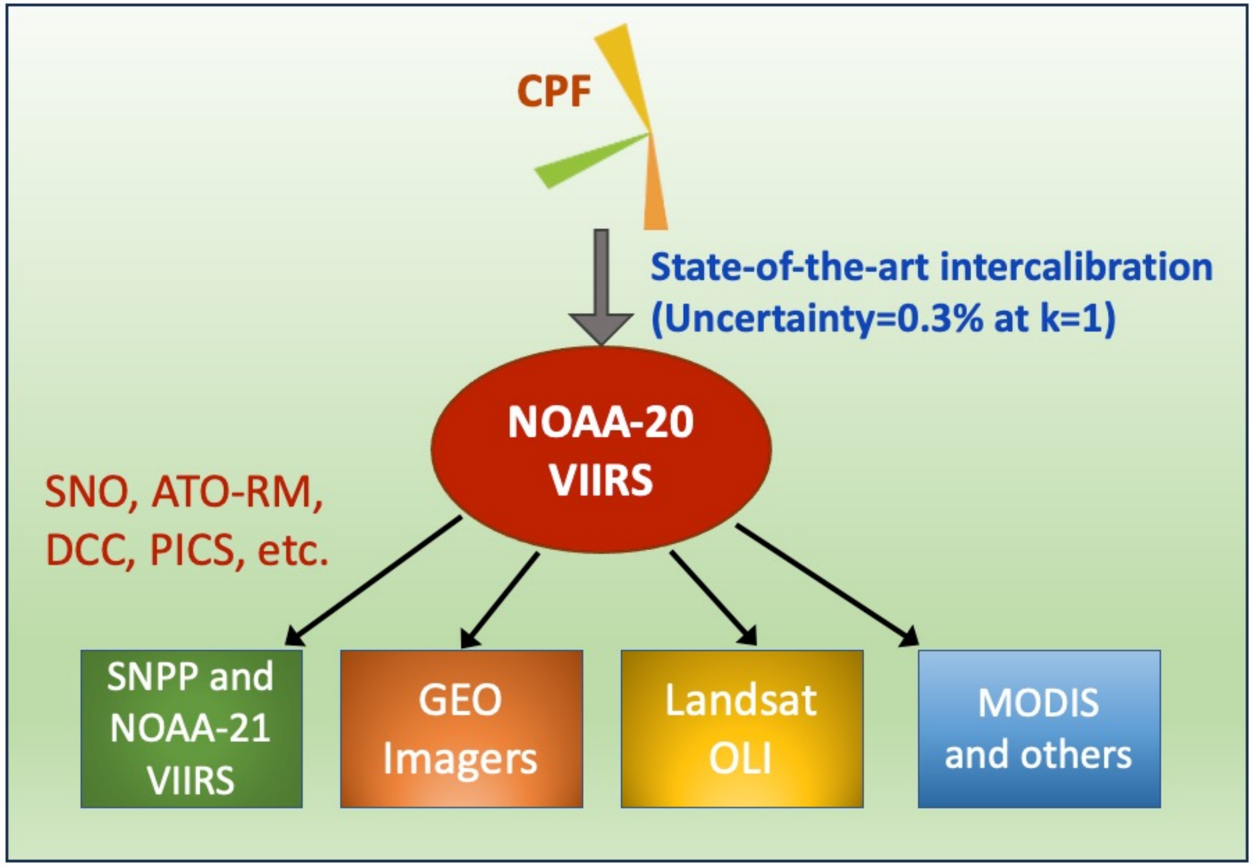
Goldin and Lukashin (2016)
Goldin et al. (2019)
Sun et al. (2018)
Sun et al. (2015)

PDM Application Module

- Uses VIIRS scene characterization info from L2 files, identifies correct PDM LUT and retrieves DOP/AOLP estimates from ePDMs & tPDMs
- Can be used to support several applications outside the CPF project

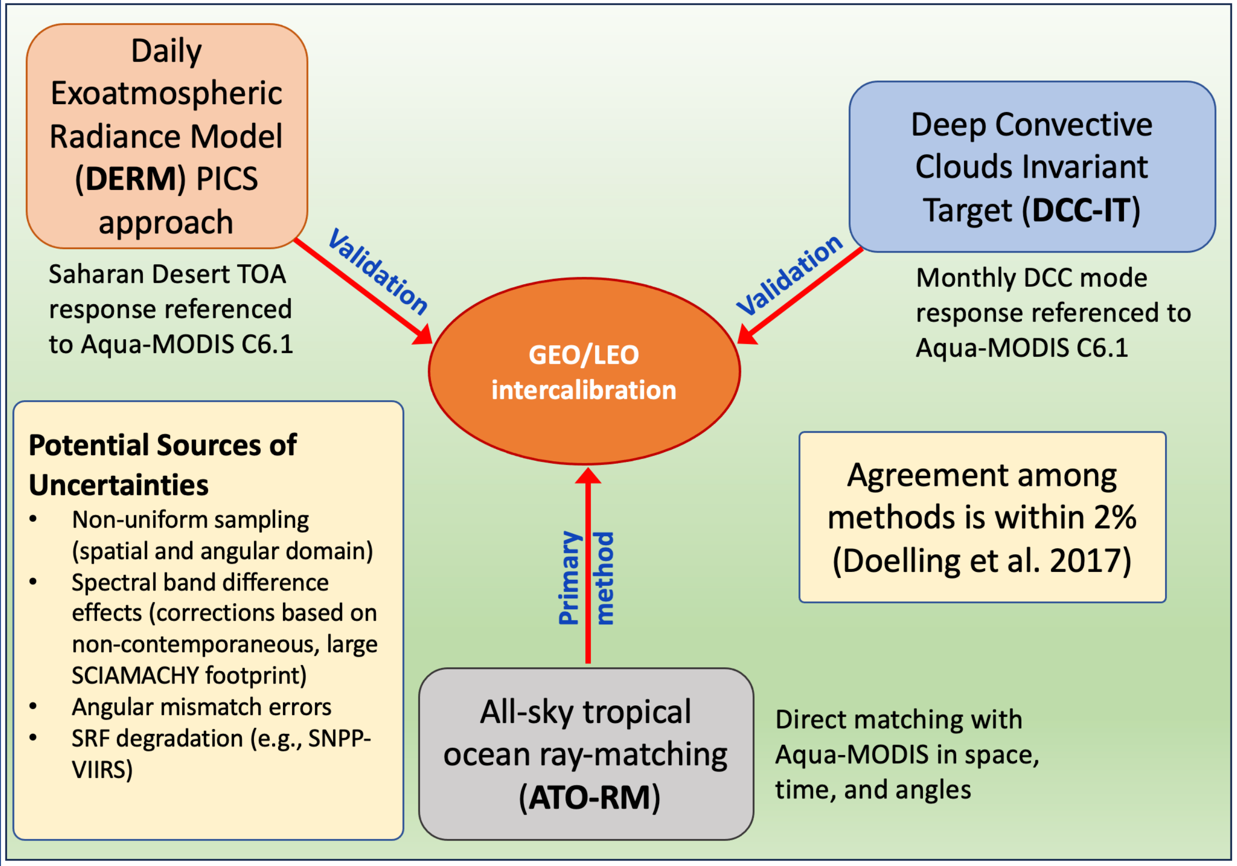
CPF will enable other Earth observing missions to surpass their original capabilities

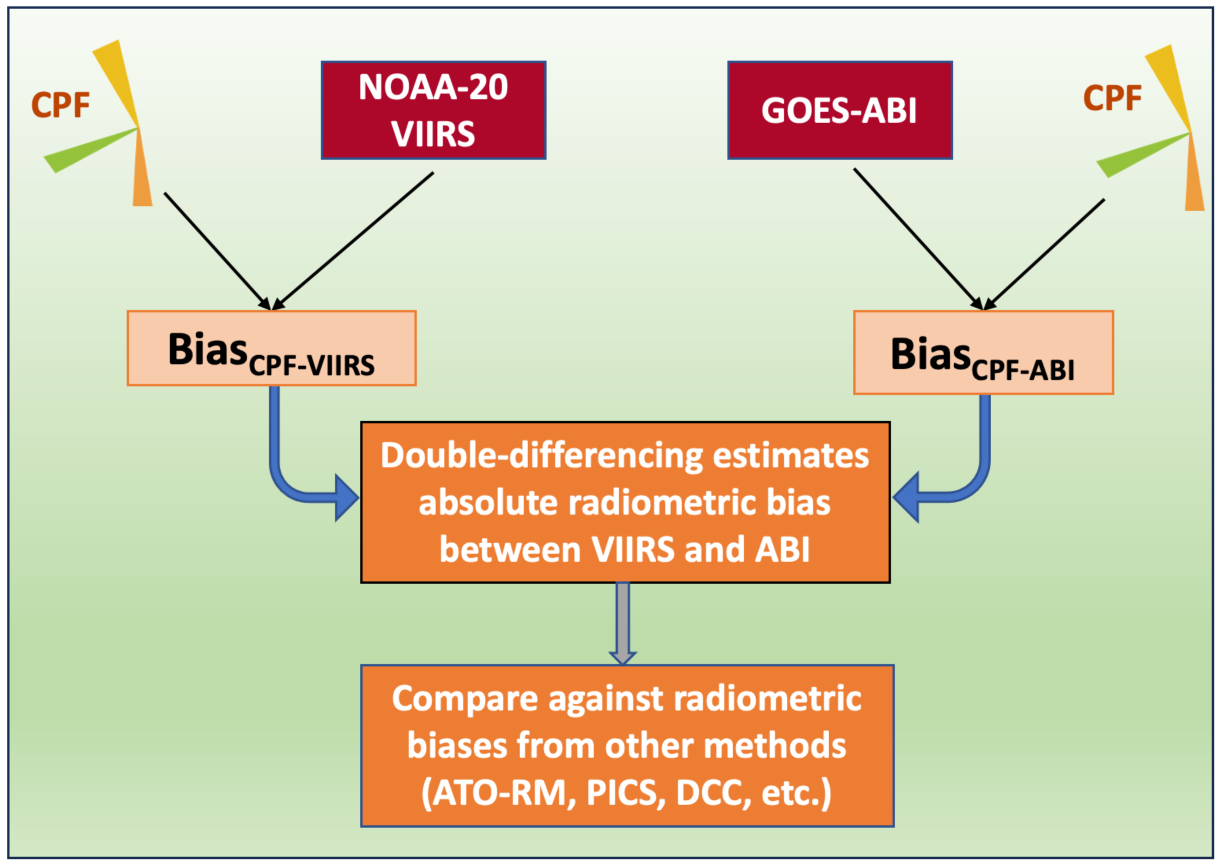




- Improved reference instrument for satellite intercalibration community
- Aid the community with an independent assessment of the radiometric accuracy of VIIRS sensors (onboard SNPP, NOAA-20, and NOAA-21 platforms)
- CPF calibration transfer to several other orbiting sensors (including MODIS) via direct approach or using VIIRS as a transfer radiometer (slightly higher uncertainty)

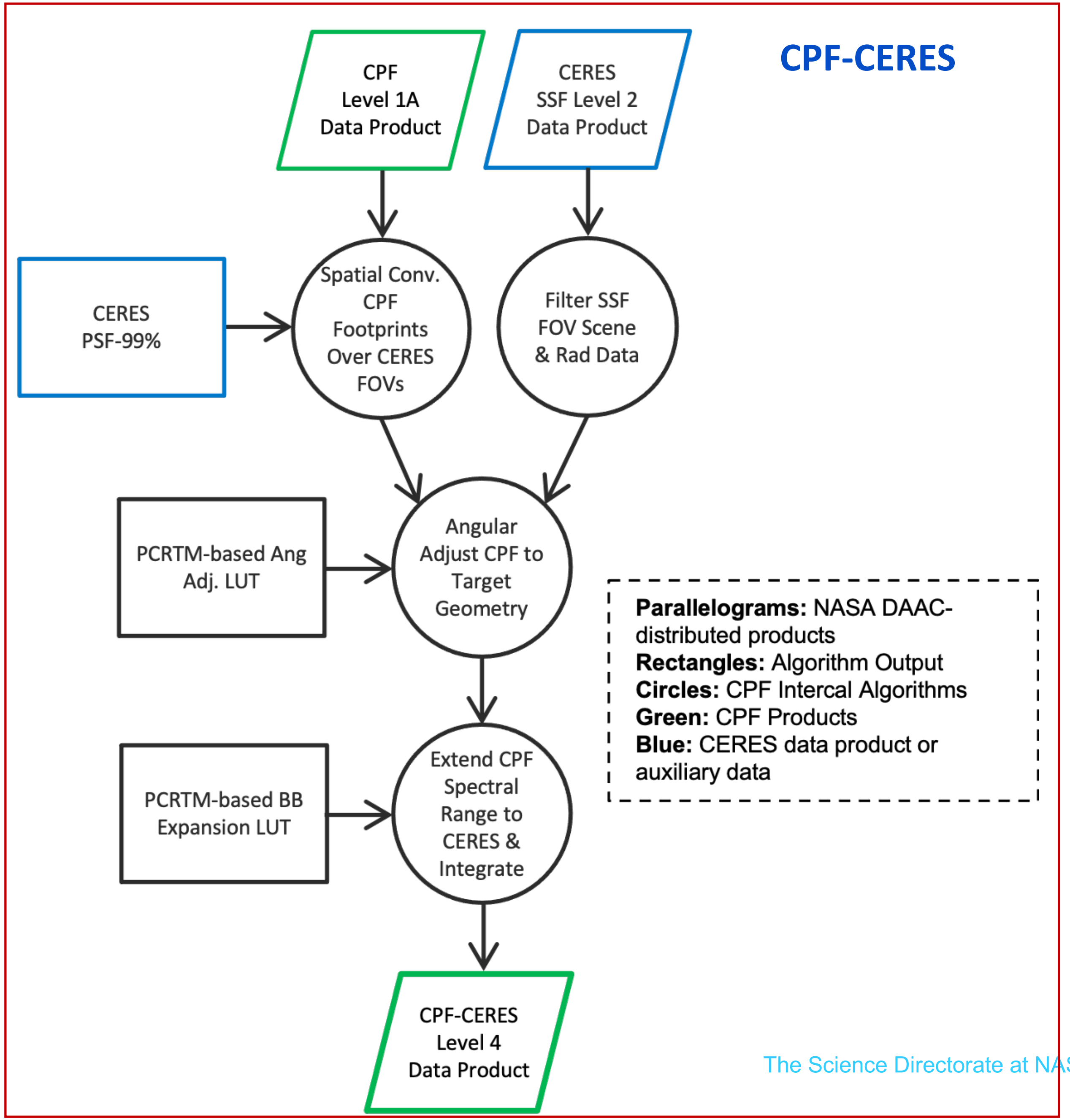
CPF supports validation of existing methods

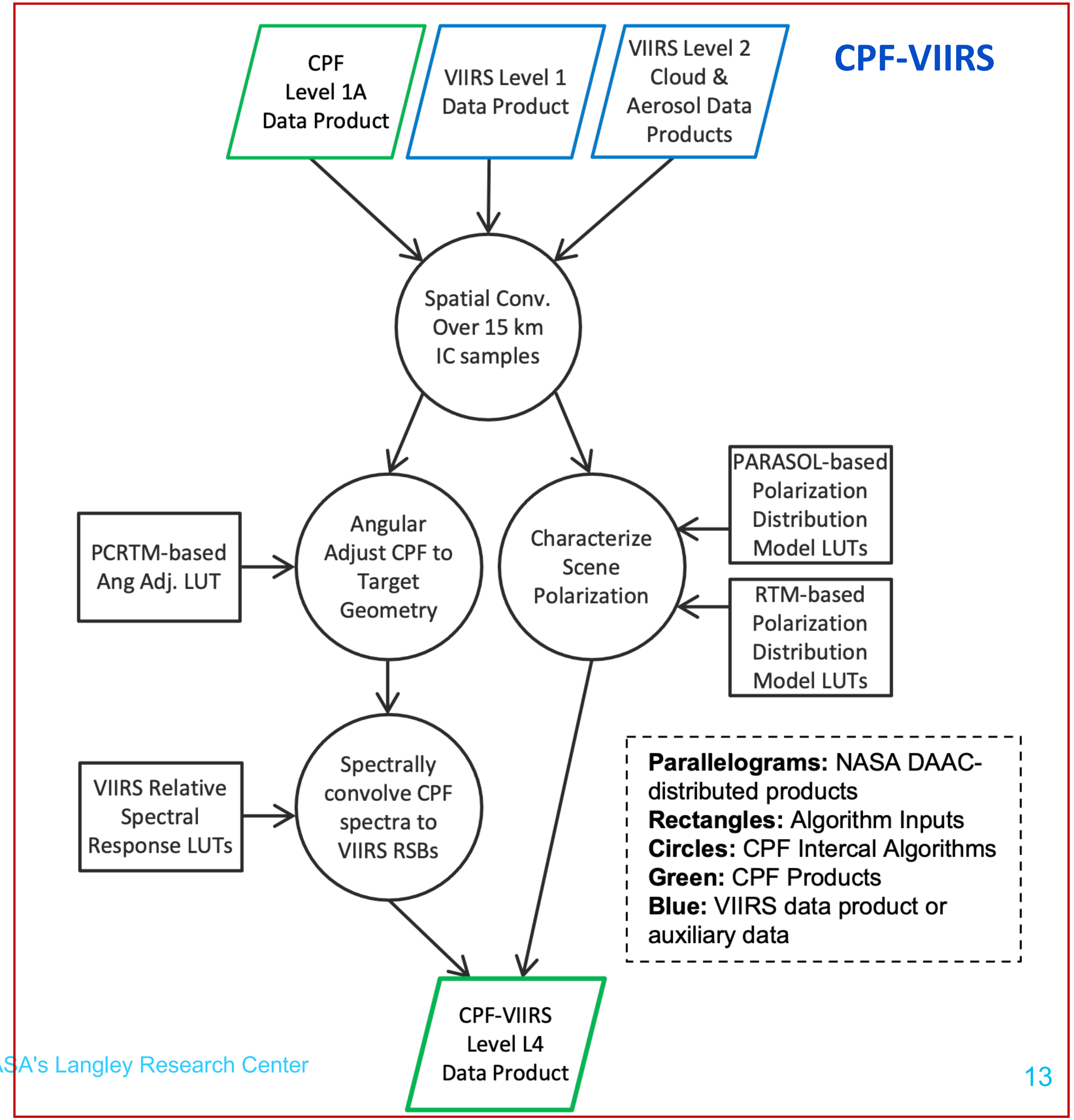




- Existing intercalibration methodologies can be validated by concurrently (same month) calibrating two instruments against CPF
- CPF will help split uncertainty sources and optimize intercalibration methods for different wavelengths
- Ultimately, these methods can be used to transfer CPF reference to future as well as past instruments

Intercalibration Algorithm Flowcharts





Summary and Path Forward

CPF stands out for cutting-edge fusion of spectral coverage, spectral/spatial resolution, and radiometric accuracy

CPF's innovative approaches to address the challenges of multidimensional data mismatching between CPF and target enables the attainment of intercalibration accuracy that was previously unprecedented

*Maintain collaboration with GSICS and advocate for global adoption of CPF as **preferred reference***

Enhance the spectral and radiometric characterization of Pseudo-Invariant Earth Targets (e.g., key desert sites, Deep Convective Clouds) - Potential for additional data product

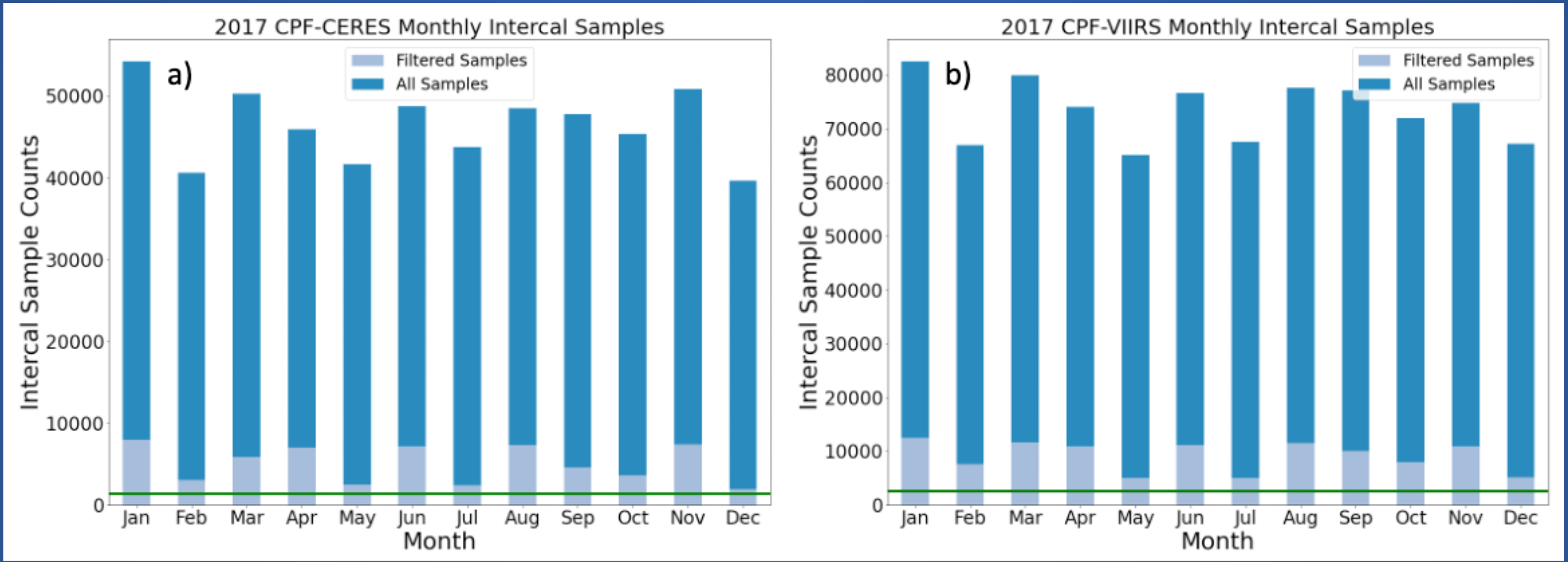
Aid in the enhancement of the Lunar Calibration models by supplying high-accuracy Lunar reflectance measurements obtained from CPF - Potential for additional data product

Expand the utilization of CPF's innovative intercalibration methods/tools (LASICS, PDMs) to additional sensors and use cases

Collaborate with CERES IGCG in maintaining Langley global leadership within intercalibration community

Anchor existing NASA Investments (e.g., MODIS) with the SI-traceable Calibration Standard of CPF, leading to an enhanced multi-decadal climate data record - Potential for additional data product

Intercalibration Sampling Estimates from low-fidelity simulation data for year 2017



Sample selection criteria

- a) SZA<60° and VZA <60° to ensure high signal-to-noise ratio;
- b) 5°<RAA<175° to avoid hotspot and sun glint conditions;
- c) a spatial homogeneity factor of less than 0.2 for visible wavelength (0.65 μm) to exclude extreme heterogenous scenes;
- d) spatial field of view coverage of greater than 95%;
- e) maximum allowable time difference of 10
- f) DOP<0.1 for VIIRS

Green line represents minimum required sample size to meet uncertainty threshold